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A century of earthquakes in the Dalton-Gunning region of New South Wales

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The Dalton–Gunning region of New South Wales (34.5–35.0° S, 148.5–149.5° E) is one of the more seismically active areas in Australia. Reports of felt earthquakes which occurred there in 1888, 1934 and 1984 were used to draw up isoseismal maps using the Modified Mercalli Scale (MM) of intensity. Magnitudes of 5.3, 5.6 and 4.4 were computed from the radius of perceptibility of each earthquake, and epicentral co-ordinates were assumed to be coincident with the centre of the highest isoseismals. These, and other earthquakes of magnitude 4.0 or greater that are known to have occurred since 1886, are tabulated to enable more accurate earthquake risk analyses to be undertaken for the region. Extreme-value analysis of the hundred years of earthquake data yields magnitudes of 3.3, 4.6 and 5.8 for the 1, 10 and 100 year return periods in the region. These data are extrapolated to compute a return period of 120 years for a large, potentially damaging, earthquake of magnitude 6.0 or greater.

Introduction

The 9 August 1984 'Oolong' earthquake (Gaull & Michael-Leiba, 1985) was the latest in a series of damaging earthquakes in the Dalton-Gunning region of New South Wales during the last 100 years (Burke-Gaffney, 1952; Drake, 1974). Isoseismal maps have been compiled for seven of these earthquakes (Everingham & others, 1982; Rynn & others, 1986) and three more are presented here; one for the recent 9 August 1984 Oolong earthquake (Gaull & Michael-Leiba, 1985) and the others for the larger and earlier earthquakes of 18 November 1934 and 5 July 1888. The maps for the two earlier earthquakes are based solely on contemporary newspaper accounts as, in those days, seismographs were not widely established and the maps yield reasonable epicentres, magnitudes, and focal depth. The macroseismic epicentre is defined here as the centre of the highest isoseismal contour with an assumed epicentral uncertainty equal to the radius of that contour. These distances are 25 km and 20 km for the 1888 and 1934 earthquakes respectively. The radius of the circle equivalent in area to that enclosed by the MM III isoseismal line is defined after McCue (1980) as the radius of perceptibility. The magnitudes of these two earthquakes were determined from the radius of perceptibility with an uncertainty of ±0.3 (McCue, 1980) while the focal depths were assumed to be shallow as are those computed for recent earthquakes.

With this information these important early earthquakes can be incorporated into modern earthquake catalogues and, by greatly extending the sample period, they can be used for more meaningful earthquake risk analyses. Table 1 contains all known earthquakes of magnitude ML 4.0 or greater that have occurred in the Dalton-Gunning zone since 1886 and was compiled largely from the Bureau of Mineral Resources (BMR) data file, Drake (1974), Everingham & others (1982) and Rynn & others (1986). Intensities of MM VII or more have occurred four times and MM VIII on two occasions (in 1934 and 1949).

The computation of more accurate epicentres has only been possible since October 1958 (Cleary, 1967) when the Australian National University and Snowy Mountains Hydroelectric Authority commenced the installation of a nine station seismograph network to monitor seismic activity in the Snowy Mountains. Currently, with four portable seismographs operated by the Bureau of Mineral Resources (BMR) between Dalton and Gunning (inset Figure 6), uncertainties in epicentre, magnitude and depth are of the order of ±2.0 km, ±0.2 and ±5 km respectively; the big advance over the last three decades has been the reduction in the detection threshold from magnitude ML 4.5 to magnitude ML 1.0 or less.

Maps of epicentres within New South Wales published recently (Kennett, 1985) for each year since 1958, highlight the relatively high seismic activity in the Dalton–Gunning region compared with the general background activity of the eastern highlands.

There is as yet no obvious explanation for this spatial clustering of intraplate earthquakes; the three large north-west to north-north-west striking lineaments clearly visible on LANDSAT photographs appear to have no causal association with the seismicity. A seismic refraction survey through the zone (Finlayson & McCracken, 1981) found no anomalous velocities or variations in crustal thickness.

Isoseismal maps

The 5 July 1888 earthquake

Cleary (1967) followed Burke-Gaffney (1952) in assigning this earthquake to the Robertson-Bowral region of NSW though the limited number of newspaper reports, 22 in all, indisputably point to Yass and Gunning, 100 km to the west, as being the towns closest to the epicentral region.

The only damage report emanated from Yass, where the walls of a row of houses were reported to be split by the shock (The Yass Courier, 10 July, 1888), but the type and quality of building materials were not specified.

The earthquake was felt as far away as the northern suburbs of Sydney and at Orange, but not at Cooma or Wagga, so it was smaller than the 1886 earthquake (Rynn & others, 1986) and the later 1934 event discussed below. The isoseismal map presented here in Figure 1 is not well constrained but a magnitude of ML 5.3(I) has been derived from the radius of perceptibility (McCue, 1980).

The 18 November 1934 earthquake

The lead story in the Sydney Morning Herald of 20 November 1934 stated: 'Probably the severest earthquake recorded in New South Wales was experienced at 8 o'clock yesterday morning when a wide area of the state was shaken'.

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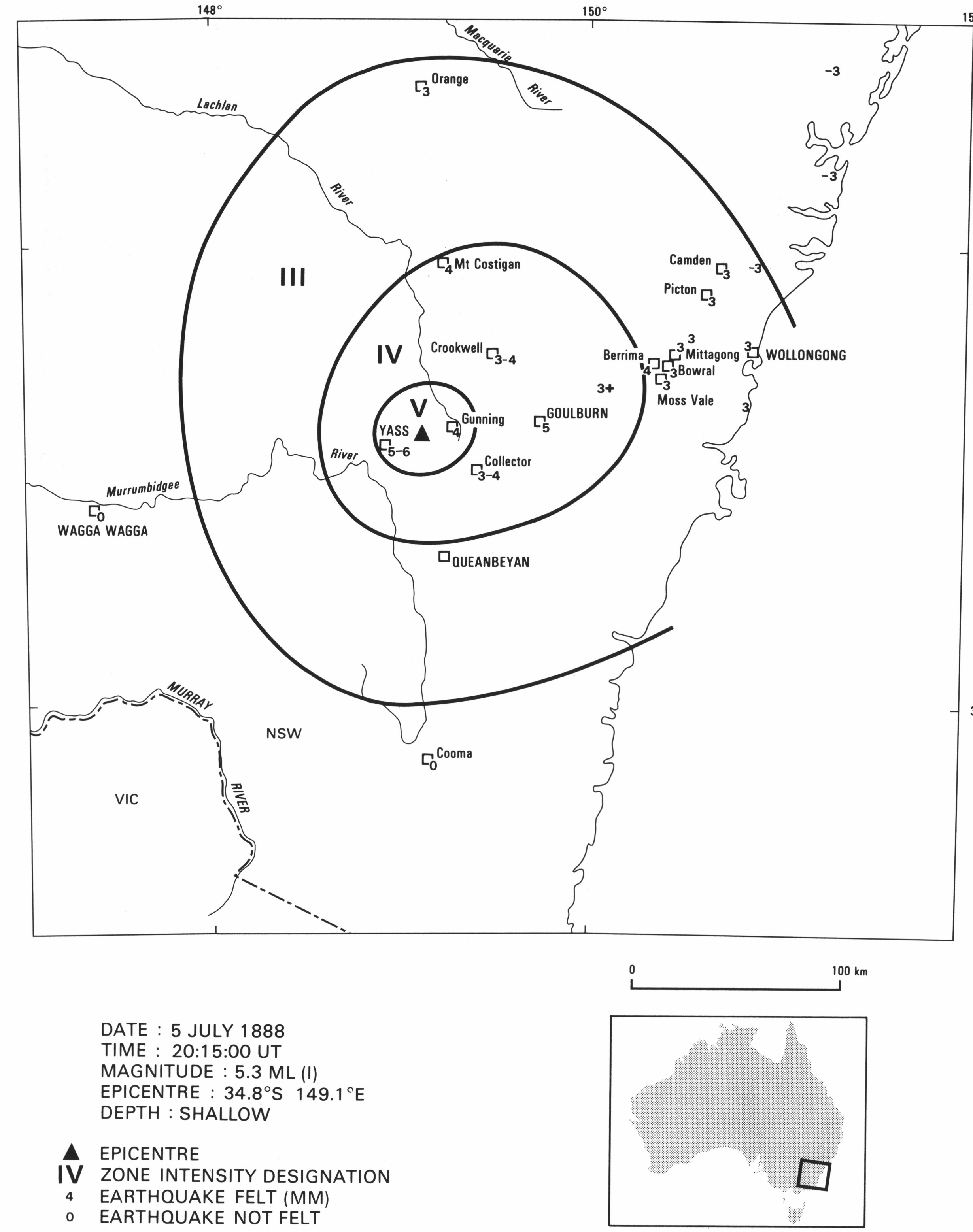

Figure 1. Isoseismal Map, 5 July 1888 Earthquake

It continued: 'The worst damage was reported from Gunning where practically every brick and stone building received damage in some form, huge rocks were split, trees were felled, and great fissures were opened in the ground.'

The earthquake was the culmination of a week-long series of foreshocks and was reported to be the worst shock in the history of Gunning. It was followed by a long series of aftershocks, one of which, on Sunday 25 November was felt at least as strongly in Cooma, 160 km distant, as was the main shock.

Several buildings in Gunning lost chimneys and one baker's oven was so badly cracked that it was rendered useless. In many houses the walls cracked and plaster fell from the ceilings. Pictures on walls were dislodged and in some

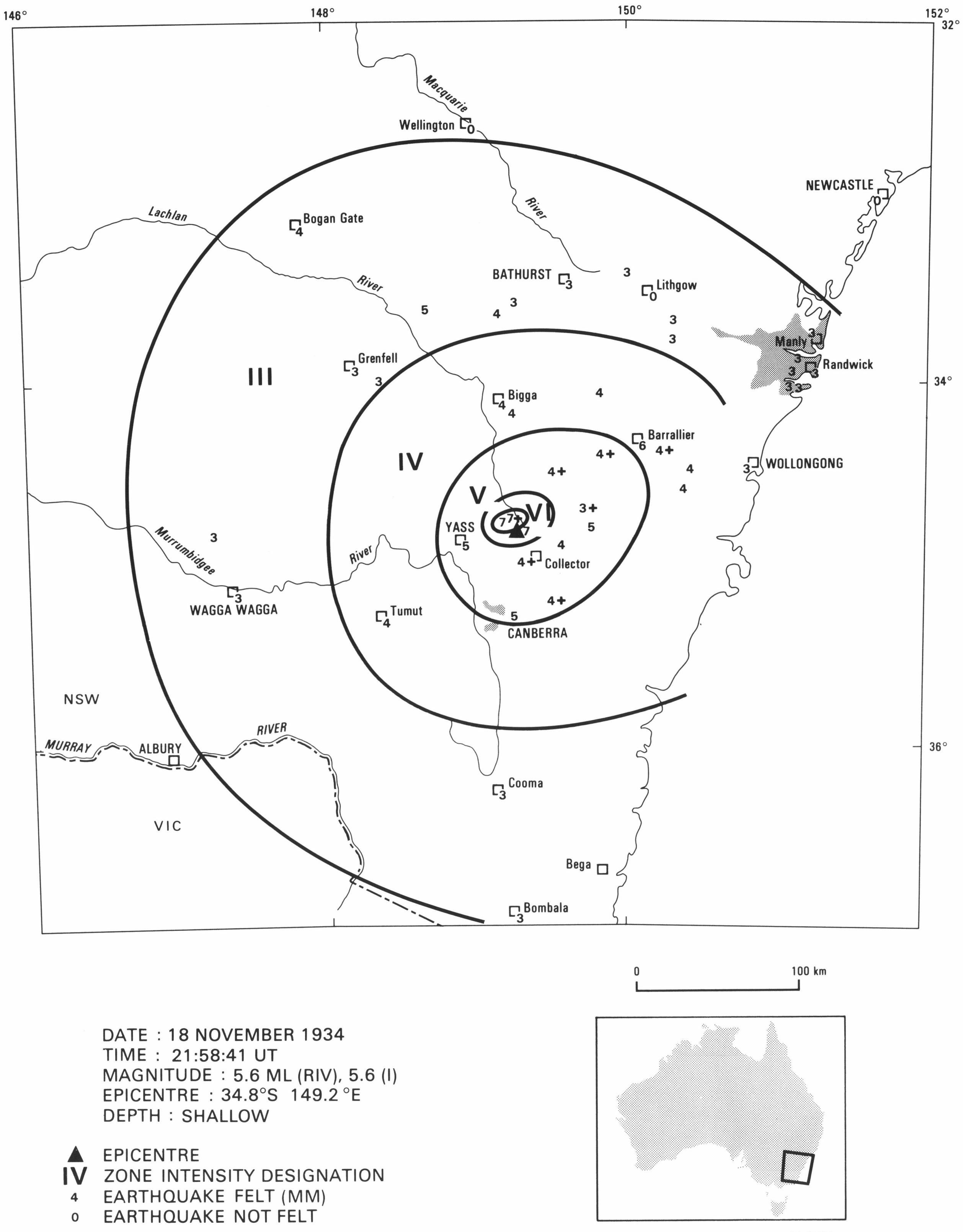

Figure 2. Isoseismal Map, 18 November 1934 Earthquake

instances turned right round. These reports are commensurate with an intensity of VIII on the Modified Mercalli Scale. At Dalton the damage was reported to have been extensive though no details were given.

According to the Canberra Times, the water in the Canberra swimming pool (at Manuka) was considerably agitated and in the pool office the telephone wobbled enough to tinkle the bell as if it were ringing. Early morning strollers reported that the road appeared to be undulating and trees vibrated violently.

The Sydney Morning Herald reported that: ‘deep fissures appeared in the road between Dalton and Gunning in four places. The fissures apparently run for a considerable distance and although they are mere cracks in some places, they are several inches wide in others.' Cracks were also reported to have opened on a ridge 3 km west of Gunning but afterwards closed up. From this brief newspaper description it is impossible to determine whether these cracks are indicative of primary faulting or just secondary fractures caused by local settlement; undoubtedly the focus of the earthquake was very shallow.

Large granite boulders were reported to have split asunder just west of Gunning. P. Chopra suggested (personal communication) that these rocks had weathered completely through along frost and joint fractures and simply collapsed as a result of the intense shaking.

According to the Sydney Morning Herald, residents in practically all suburbs of Sydney felt the tremor. No mention was made in the Newcastle papers of the tremor being felt locally, nor was it felt at Wellington or Albury; yet at Bombala, a similar distance to the south, it was felt at intensity III. A smoothed isoseismal map was compiled from 43 reports in local newspapers including 'The Sydney Morning Herald', 'Canberra Times', 'Goulburn Penny Post', 'Lithgow Mercury',

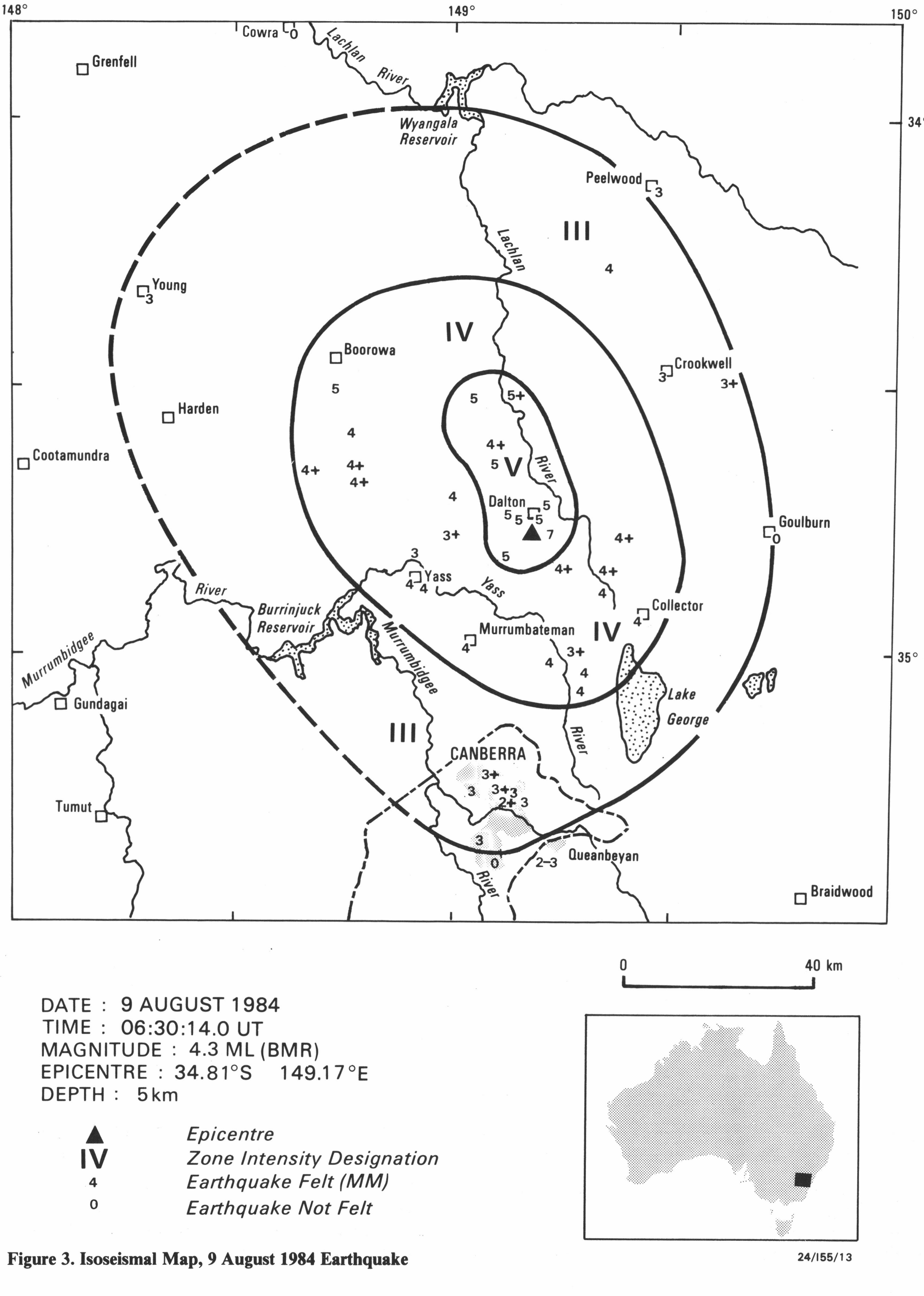

Figure 3. Isoseismal Map, 9 August 1984 Earthquake

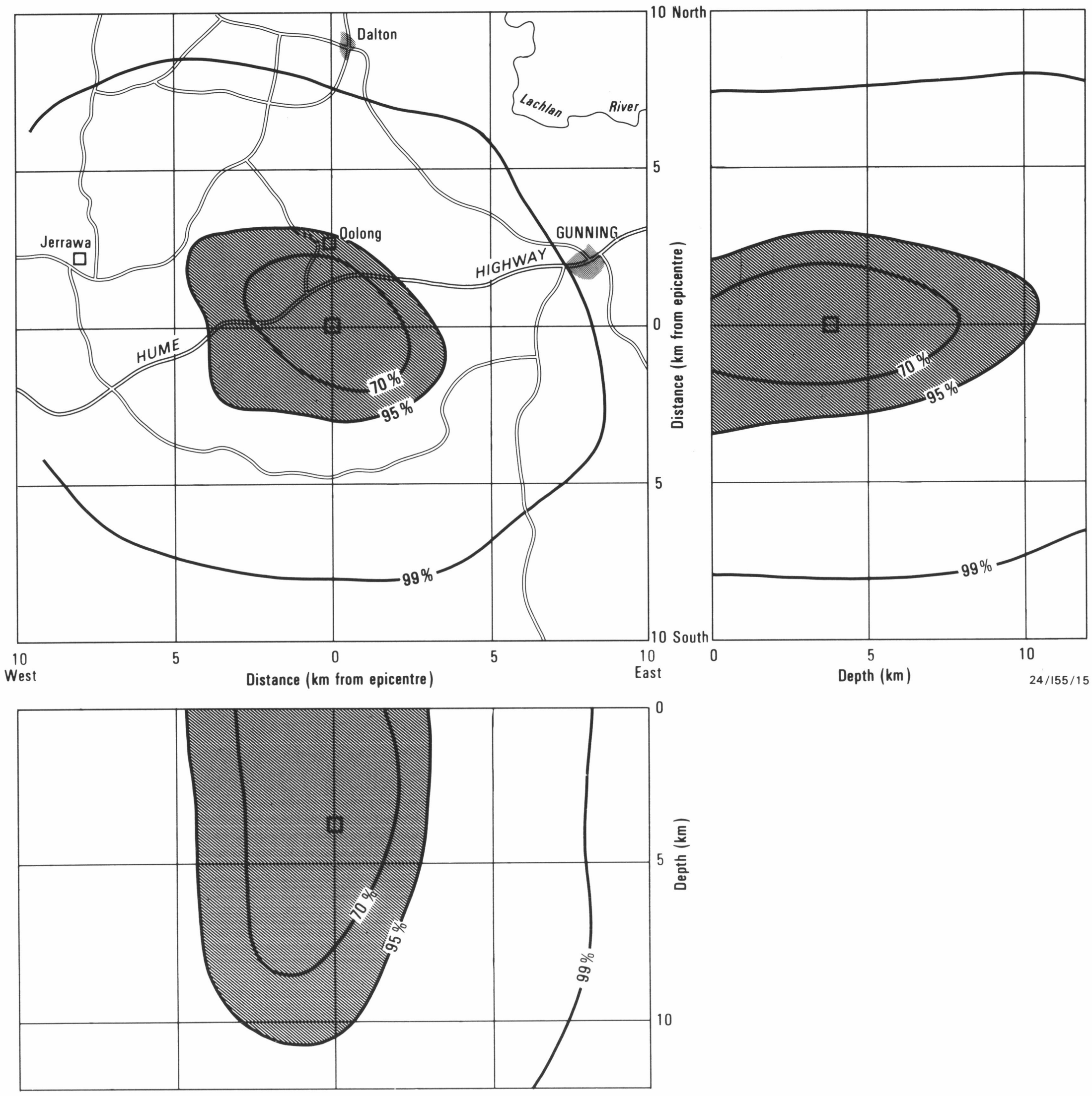

Figure 4. Confidence regions for the hypocentre of the 1984 August 9 event near Oolong determined by the method of Sambridge & Kennett (1986).

The contours enclose the regions in which the statistical confidence levels for the occurrence of the hypocentre are 70, 95 and 99 per cent, the 95 per cent region is shaded.

Table 1. Earthquakes in the Dalton–Gunning region 1886–1985, ML 3.9

Date	*Time (U.T.)*	*Lat (° S)*	*Long (° E)*	*ML**	*Maximum Intensity+*
1886 11 29	1700	34.8	148.8	5.5(I)	VII
1888 07 05	2015	34.9	148.8	5.3(I)	VI
1907 02 20	1730	34.8	149.2	4	IV
1924 03 06	2345	34.9	149.0	4.0(I)	V
1930 10 27	020351	34.5	149.0	5.0(RIV)	
1933 01 11	201051	34.8	149.2	4.8(RIV)	
1934 01 30	202754	34.8	149.5	4.7(RIV)	
1934 11 10	234740	34.8	149.2	4.8(RIV)	
1934 11 18	215841	34.8	149.2	5.6(RIV)	VIII
1934 11 21	063206	34.8	149.2	4.8(RIV)	
1947 05 05	094348	35.0	149.5	4.5(RIV	
1949 03 10	223033	34.8	149.2	5.5(RIV)	VIII
1952 09 07	054114	34.8	149.3	4.7(RIV)	
1952 11 18	100306	34.8	149.3	4.4(RIV)	
1952 11 19	015916	34.8	149.3	4.9(RIV)	V
1952 11 22	075720	34.8	149.3	4.6(RIV)	
1971 11 03	200536	34.78	149.17	4.3(RIV)	VI
1977 06 30	124822	34.67	148.87	4.2(BMR)	IV
1977 07 04	200520	34.65	148.89	5.0(CAN)	VI
1984 08 09	063013	34.80	149.17	4.4(BMR)	VII

* RIV Drake's (1974) reading of the Riverview Seismograms
CAN Australian National University
(I) Derived from intensity data.
\+ Modified Mercalli Scale

'Adelong and Tumut Express and Adelong Argus', 'Bombala Times', 'Cooma Express' and 'Queanbeyan Age'. The radius of perceptibility was about 250 km (Fig. 2) which converts empirically to a magnitude of ML 5.6(I) (McCue, 1980). This is identical to the Richter or local magnitude Drake (1974) measured from the Riverview seismograms. The locations of identified foreshocks and aftershocks in Table 1 have been set the same as the mainshock.

The 1984 Oolong earthquake

The earthquake struck at 4.30 pm on 9 August causing extensive cracking in a brick homestead at Oolong and the Anglican Church in Dalton, both of which had suffered previous damage during the 1949 earthquake (Table 1). Shaking was felt over an average radius of about 70 km (Fig. 3), which corresponds to a magnitude of ML 4.4(I). A similar magnitude of ML 4.3 was determined at the BMR from eastern Australian seismograms.

Using a simple model for the entire southeast Australian region (Doyle, & others, 1959), the preliminary location from the Australian National University (ANU) Bulletin No. 28/84 was determined at:

Latitude : 34.81° S
Longitude : 149.14° E
Depth : 10 km

For convenience in travel-time calculations, the BMR used an averaged model (Table 2) based on the Finlayson and McCracken (1981) data but without low velocity zones, and determined a hypocentre at:

Latitude : 34.81° S (±0.02)
Longitude : 149.17° E (±0.02)
Depth : 5.3 km (±5.2)

about 3 km away from the preliminary estimate. This estimate is in excellent agreement with that obtained using the direct search scheme of Sambridge & Kennett (1986):

Latitude : 34.81° S
Longitude : 149.18° E
Depth : 3.8 km

The 70, 95 and 99 per cent confidence regions associated with this solution are shown in Figure 4, by the shaded region in map view and in the north-south and east-west sections through the hypocentre.

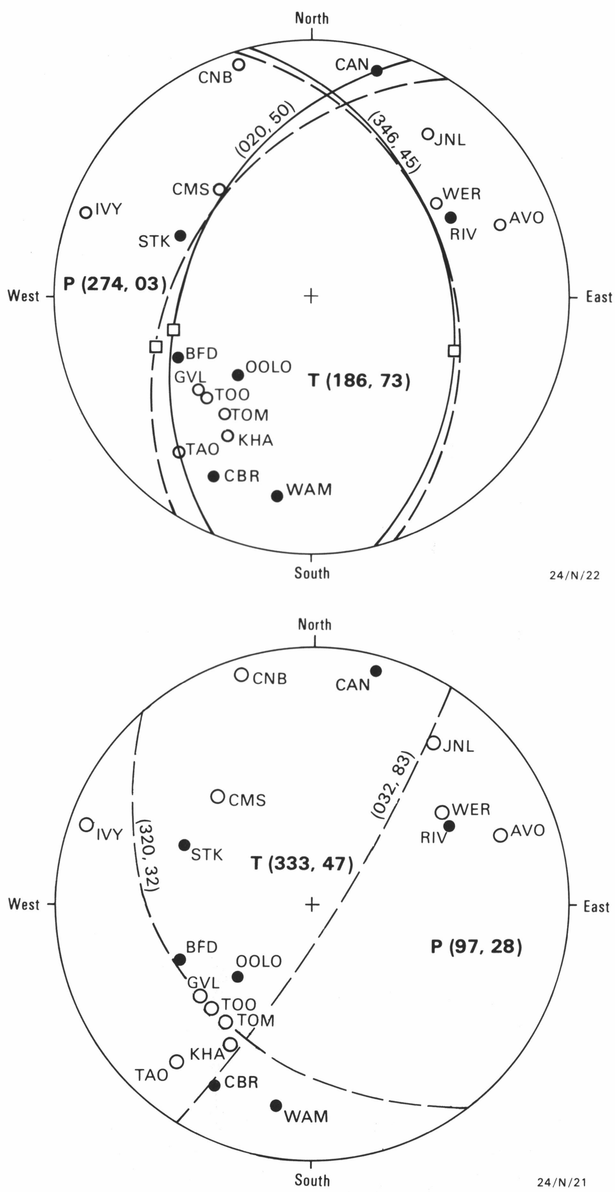

Figure 5. Focal mechanism solutions for the 9 August 1984 earthquake.

Open circles represent dilatations, full circles compressions and crosses emergent arrivals. P,T are the largest and smallest principal stress axes respectively.

Table 2. Crustal model in the Dalton-Gunning region

Depth km	Velocity km/s	
	Vp	Vs
0		
	5.80	3.35
10.5		
	6.30	3.64
26.5		
	6.90	3.98
31.0		
	7.35	4.24
50.0		
	8.08	4.66

An SMA-1 accelerograph at Oolong was triggered by the earthquake and by 20 of the aftershocks. Normally, the P-wave arrival on these instruments is lost because there is a start-up delay of at least 0.1 s so the data cannot be used for locating earthquakes. However, in this sequence, two of the aftershocks were only 5 seconds apart so the instrument was still operating from the first shock when the second began. A clear S-P time of 0.4 s was observed in this case corresponding to a slant distance of about 3 km from Oolong and in fair agreement with the computed distance.

The centre of the MM V isoseismal is at 34.66° S, 149.14° E, within 13 km of the computed epicentre which is within the estimated error of ±20 km quoted in the introduction.

In this case a unique focal mechanism solution could not be determined due to the small amplitude of the refracted (Pn) first arrivals on distant seismograph stations and, conversely, such a large, impulsive, direct P arrival on close stations; the photographic recording trace simply disappeared and no direction of motion could be read even under a microscope. The eighteen remaining first arrivals were plotted onto a lower hemisphere projection of the focal sphere and the plot indicates the two possible fault plane solutions illustrated in Figure 5. In each case, three of the eighteen polarites are incompatible with the solution; RIV, STK and KHA in the upper solution, and RIV, CNB and CMS in the lower one. There was no observed surface faulting to indicate which of the nodal planes was the fault plane. The only consistent features of these two focal mechanisms are the east-west direction of the principal stress and the compressive nature of the failure. This agrees with other focal mechanisms computed for Dalton–Gunning zone earthquakes (Denham & others, 1981) and downhole stress measurements in the region (Chopra, 1985).

Spatial extent of epicentres

The plot in Figure 6 shows that epicentres located between 1960 and 1984 are scattered over two distinct zones of spatial extent 10 km, one north of the Castle Hill (CAH) seismograph station, the other south of Dalton. The southern zone is the more active of the two. It will be interesting to see whether the gap between the two zones is still evident through the next decade or so.

Focal depth distribution

During 1985/86 up to four additional seismographs were deployed by BMR in the Dalton region (inset Fig. 6). Using data from these seismographs to supplement the Australian National University data and using a local crustal model

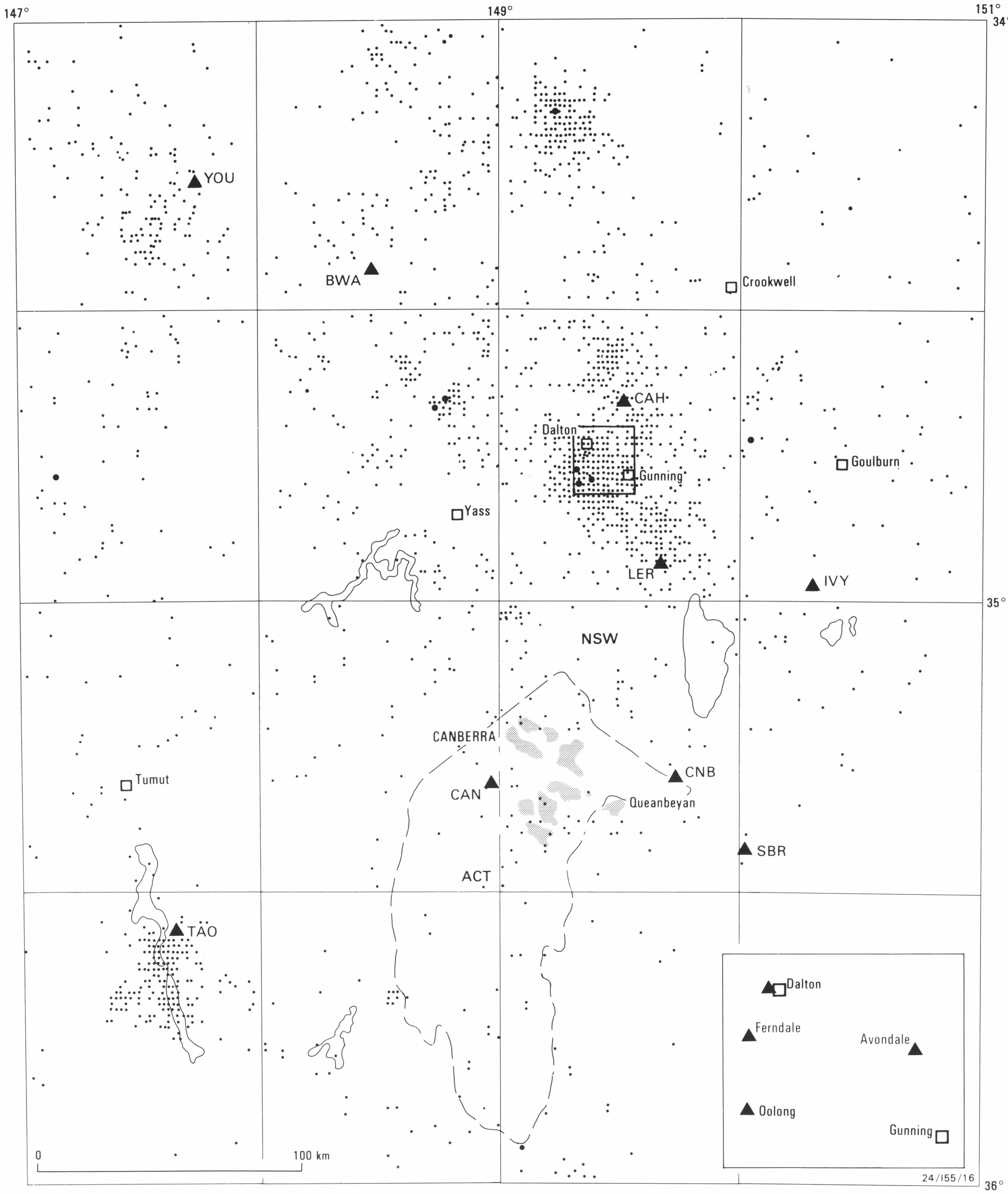

Figure 6. Plot of epicentres in the Dalton–Gunning Region (34–36° S, 148–150° E), 1950–1984.
Triangles represent seismographic stations operated by the Australian National University, except CNB which is operated by BMR. The inset shows the location of four temporary seismographs operated by the BMR during 1986.

(Finlayson & McCracken, 1981) in the computer location program, better focal depth control has been achieved. The histogram of Figure 7 summarises focal depths of 53 microearthquakes which occurred in the Dalton area during the period 1 April 1986 to 30 November 1986 and which are located by at least 5 stations. Focal depths ranged from 0 to 11 km with a mean of 1 km and most (64%) had a very near surface depth (0 to 1 km).

The shallowness of these small events is attested by the fact that at least 24 of them were felt by Dalton residents, 14 with intensities of MM IV, and another two (one of which had a magnitude of only ML 1.5) with an intensity of MM V! The smallest felt event had a magnitude of ML 1.0.

Records from portable digital recorders deployed by the Australian National University in November/December 1984

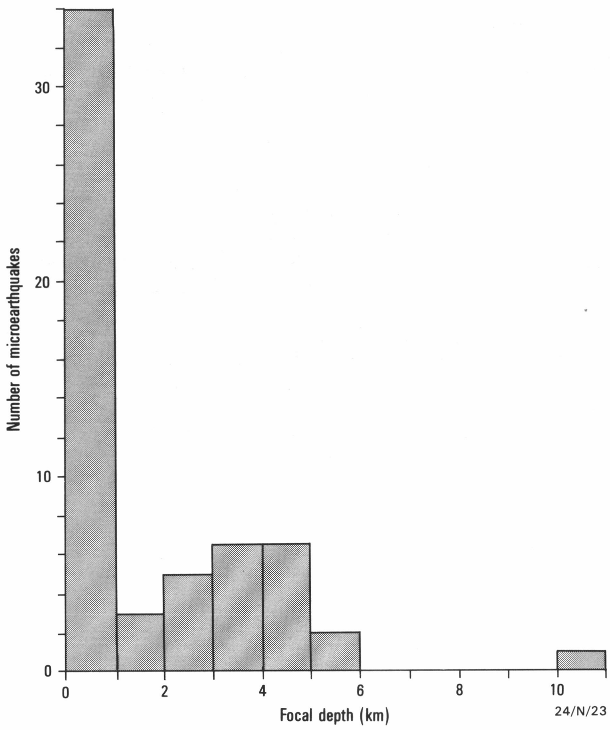

Figure 7. Histogram of focal depths for 25 microearthquakes located in 1986 using additional data from the four-station microearthquake network shown in Figure 6.

showed then that these small events were shallower than 2 km depth. Furthermore, the ML 3.1 earthquake which occurred on 7 January 1986 at 34.76°S, 149.18°E (4 km south of Dalton) had a computed depth of 2(±3) km. It was felt with a maximum intensity of MM IV-V at Dalton, and it dislodged plaster in the Anglican Church from cracks caused by the 1984 Oolong earthquake. A similar intensity was experienced at Oolong, 2 km to the southwest of the epicentre.

Apparent frequency of earthquake recurrence

The earthquake history of the Dalton/Gunning zone is probably complete for the following time-magnitude sets: ML>4.9 since 1886, ML>4.4 since 1909, when seismographs were installed at Riverview, and ML>1.9 since 1961, when a seismograph was installed at Dalton. The completeness of the two larger magnitude sets over the stated time periods was confirmed using the test devised by Stepp (1972).

Excluding aftershocks, there have been six earthquakes of at least magnitude ML 5.0; the largest at magnitude ML 5.6 was that of 1934 which caused considerable damage to domestic structures in Gunning and Dalton. From Table 1 and the post-1958 ANU data file, the set of largest annual earthquakes was compiled and fitted, using least squares, by a Gumbel (1958) Type 1 extreme-value distribution which is plotted in Figure 8. The equation of the line of best fit is:

$$-\ln(-\ln P) = \beta M - \ln\alpha$$

where P is the probability that the largest earthquake in any year is less than M and α and β are constants. The left hand side of this equation is termed the reduced probability. The slope of the curve 'β' is b ln 10 where 'b' is the slope of the familiar recurrence relation, relating the number of large to small earthquakes. A b-value of 0.81 (±0.02) was obtained which is not significantly different from the value

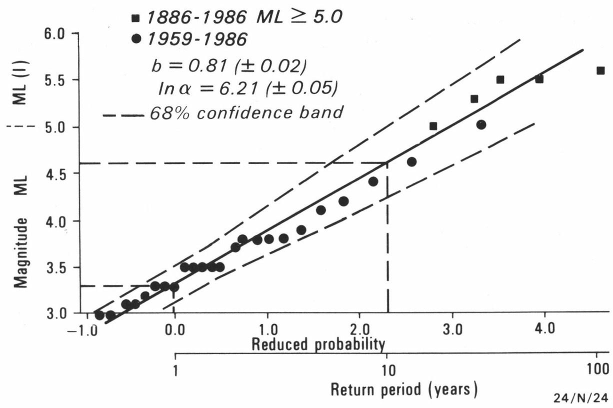

Figure 8. Gumbel type 1 extreme-magnitude distribution of the set of largest annual earthquakes in the Dalton-Gunning region, 1886–1985.

of 0.80 found by Gaull & Michael-Leiba (personal communication) during a new study of the seismic risk in the region. With this 'b' value and a value of lnα of 6.21 (±0.05), return periods of 1, 10 and 100 years were computed for magnitudes of 3.3, 4.6 and 5.8 respectively. Extrapolation of the 100 year data set indicates that an earthquake of magnitude 6.0 has an estimated return period of 120 ±12 years.

Large earthquakes are not unknown in eastern Australia; they have occurred in Bass Strait, in 1885 and 1892, and in Queensland in 1918 (Everingham & others, 1982).

The 100 year earthquake has not occurred in the Dalton-Gunning region in the last century; by definition there is a 37 per cent chance that an earthquake will not occur in any time interval equal to its return period and a 13.5 per cent chance that it will not occur in a time interval double the return period. Likewise, in three of the last ten decades, no earthquake has exceeded magnitude 4.0 though the computed return period for an earthquake of this size is 3.5 years.

Maximum magnitude

There is no clear increase in 'b' with magnitude in Figure 8, showing that the sample period is too short to compute a maximum magnitude but there is also no indication that it is likely to be less than magnitude ML 6.0. An earthquake of this size would cause considerable damage to domestic dwellings in nearby Dalton and Gunning where old masonry homes have already been repeatedly damaged by past earthquakes. Because the focal depths are so shallow, surface faulting would be expected to accompany such a large earthquake thereby endangering other facilities which traverse the zone such as the Moomba–Sydney gas pipeline and the Sydney to Melbourne railway.

Discussion

It is rare indeed to have in Australia as extensive an earthquake data set as the one hundred year sample in the Dalton-Gunning region. It should be possible to push the earthquake history back another 30 years or so by doing a more extensive literature search to check the stationarity of 'b' with time and magnitude.

Analysis of the data shows that the earthquakes are localised in a very small source area which has an earthquake risk comparable to that of the Southwest Seismic Zone of Western Australia (Gaull & Michael-Leiba, 1987) where earthquakes up to magnitude MS 6.8 have occurred in the last century. No earthquake has exceeded magnitude ML 5.6 in the Dalton–Gunning region since 1886 and probably not since June 1788 when the European colonisers of New South Wales felt their first earthquake at Port Jackson. However, there is no reason to suppose that an earthquake exceeding magnitude ML 6.0 is an impossible or even unlikely event.

Conclusions

Analysis of historical documents and of modern instrumental data has led to the compilation of the most comprehensive list yet published of earthquakes of magnitude ML 4.0 or more in the Dalton–Gunning region of New South Wales during the past 100 years. The list is only complete for earthquakes above magnitude ML 4.9 for the whole period, although this threshold drops to 4.4 from 1909, and 1.9 from 1960.

Macroseismic epicentres and magnitudes were calculated from intensity information based on the Modified Mercalli scale and the three new isoseismal maps bring to eleven the number so far compiled for the Dalton region.

With the aid of a four-station microearthquake network accurate focal depths of 53 microearthquakes have been determined of which 64 per cent occurred within 1 km of the surface.

Using extreme-value statistics we found the slope 'b' of the magnitude-frequency relationship to be 0.81 (±0.02) and the return period of a large magnitude ML 6.0 earthquake to be 120 (±12) years.

The largest earthquake near Dalton in the period studied occurred on 18 November 1934 and had a magnitude of ML 5.6.

Previous measurements of the regional crustal stress are supported by a fault-plane solution for the 9 August 1984 earthquake which indicates that the upper crust, at least, is under horizontal compression in an east-west direction.

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